Can Seqlocks Get Along with Programming Language Memory Models?

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Seqlocks

Read-write locks cause coherence misses on reads.
- Even reader critical sections modify lock.
- Reader critical sections need exclusive cache-line access.

Seqlocks: Readers don't update a lock data structure.
- Writers increment sequence number before and after change.
- Readers check whether writer interfered.
- If so, start over …

Used in Linux kernel, jsr166e `SequenceLock`.

Similar techniques used for e.g. software transactional memory implementations.

Seqlocks, version 0 (C++11, broken)

```
atomic<unsigned long> seq;
int data1, data2;

void writer(...) {
  unsigned seq0 = seq;
  while (seq0 & 1 ||
    !seq.compare_exchange_weak
        (seq0,seq0+1))
  { seq0 = seq; }
  data1 = ...;
  data2 = ...;
  seq = seq0 + 2;
}

T reader() {
  int r1, r2;
  unsigned seq0, seq1;
  do {
    seq0 = seq;
    r1 = data1;
    r2 = data2;
    seq1 = seq;
  } while (seq0 != seq1
           || seq0 & 1);
  do something with r1 and r2;
}
```

data races!

C++ has "catch-fire" data race semantics.
More subtly broken in Java.

Seqlocks, version 1 (correct)

```
atomic<unsigned long> seq;
atomic<int> data1, data2;

T reader() {
  int r1, r2;
  unsigned seq0, seq1;
  do {
    seq0 = seq;
    r1 = data1;
    r2 = data2;
    seq1 = seq;
  } while (seq0 != seq1
           || seq0 & 1);
  do something with r1 and r2;
}
```

Easy, principled fix.
No data races ➔ sequentially consistent
Prevents data reads from being reordered.
Expensive on POWER.
Roughly 3 x worse than optimal.
Roughly optimal on x86.
Atomic accesses to `data`*n* initially surprising, but make sense.

Seqlocks, version 2 (broken)

```
atomic<unsigned long> seq;
atomic<int> data1, data2;

T reader() {
  int r1, r2;
  unsigned seq0, seq1;
  do {
    seq0 = seq;
    r1 = data1.load(m_o_relaxed);
    r2 = data2.load(m_o_relaxed);
    seq1 = seq;  // m_o_seq_cst load
  } while (seq0 != seq1
           || seq0 & 1);
  do something with r1 and r2;
}
```

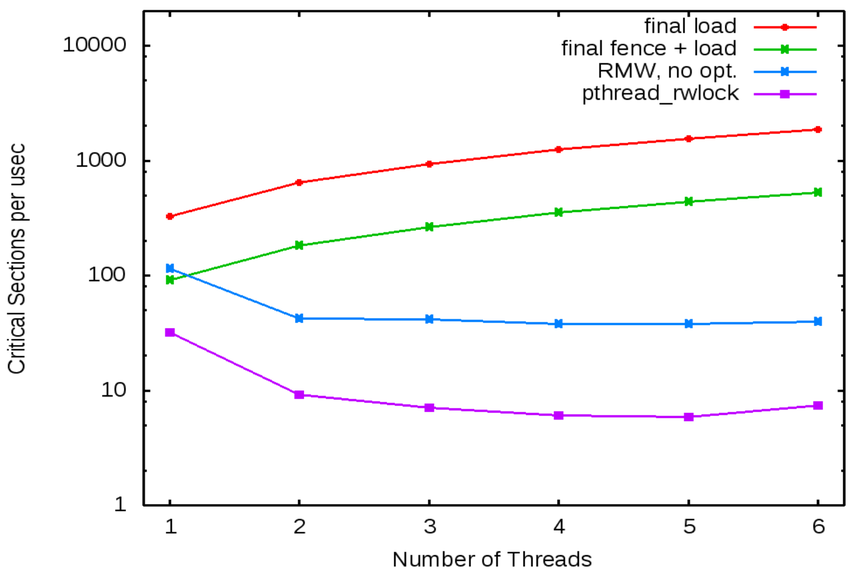
Can be reordered!
"seq_cst" load does not enforce order w.r.t. earlier ops

Seqlocks, version 3 (correct, fast, tricky, C++-only)

```
T reader() {
  int r1, r2;
  unsigned seq0, seq1;
  do {
    seq0 = seq.load(m_o_acquire);
    r1 = data1.load(m_o_relaxed);
    r2 = data2.load(m_o_relaxed);
    atomic_thread_fence(m_o_acquire);
    seq1 = seq.load(m_o_relaxed);
  } while (seq0 != seq1
           || seq0 & 1);
  do something with r1 and r2;
}
```

Seqlocks, version 4 (correct, scalable with compiler optimization)

```
T reader() {
  int r1, r2;
  unsigned seq0, seq1;
  do {
    seq0 = seq.load(m_o_acquire);
    r1 = data1.load(m_o_relaxed);
    r2 = data2.load(m_o_relaxed);
    seq1 = seq.fetch_and_add(0, m_o_release);
  } while (seq0 != seq1
           || seq0 & 1);
  do something with r1 and r2;
}
```



X86 reader performance

final load ~ seq_cst or fence version
final fence + load ~ optimized RMW (better than seq.cst. on Power)

Version 1 (seq. cst. atomics for data) is easy to write, works with C++ and Java, performs well on some platforms, not others.

Version 3 (fences) is very tricky to write correctly. Should perform well everywhere. Only for C++.

Version 4 (read-don't-modify-write) works everywhere. Scalability depends on currently unimplemented compiler optimization. With optimization: Worse than version 1 on X86, better on POWER.

Version 2 (plain relaxed data) is probably quite popular in Java, but is undeserving of its popularity.

Other languages:
C++11 really uses more verbose memory order syntax, e.g. memory_order_relaxed.
C11 memory model is essentially identical to C++11, modulo syntax.
Java volatile corresponds to atomic<T> with default seq_cst operations. Ordinary data operations behave similarly to C++ m_o_relaxed.
C# memory model is probably close enough to Java for this purpose, though it's generally considerably different.